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THE EFFECT OF CONTINUOUS KNOCK ON THE ENDURANCE OF AN AIRCRAFT ENGINE CYLINDER

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ADVANCE RESTRICTED REPORT

THE EFFECT OF CONTINUOUS KNOCK ON THE ENDURANCE OF AN AIRCRAFT-ENGINE CYLINDER

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SUMMARY

The possibility that knock causes injury to engine parts only by inducing preignition is the subject of serious controversy. An investigation was therefore conducted to determine any injurious effects of knock on engine parts. Endurance tests were run on a single-cylinder engine to compare the conditions of cylinders operated with and without knock. All tests were run at approximately the same power outputs. The intensity of knock was controlled by the selection of fuel. An oscilloscope was used to aid in detecting preignition.

Two hours of operation with violent knock were sufficient to cause severe localized disintegration of the piston and cylinder head in the regions of the end zones. Operation with light knock for 5.6 hours resulted in slight localized disintegration of the piston in the region of the intake end zone.

Operation for 25 hours under the same test conditions but with a fuel of sufficiently high grade to suppress knock resulted in no noticeable injury other than normal operating wear.

Neither the oscilloscope nor the cutting off of the ignition revealed any indication of preignition or afterfiring.

INTRODUCTION

The reason for suppressing fuel knock in internal-combustion engines is to obviate the possible destructive effects of knock on engine parts. Knock is avoided either by limiting the brake mean effective pressure and other engine-operating conditions or by using fuels of sufficiently high antiknock qualities. The possibility that knock does not cause injury directly but first induces destructive preignition has resulted in controversy regarding the methods used to prevent injury resulting from knock. If preignition must be induced to cause injury, the suppression of preignition may prevent injury under knocking conditions.

The possibility that hot-spot ignition rather than knock is the cause of injury to the engine was early mentioned by Ricardo (reference 1). He believed that preignition, brought about by persistent

knock and the consequent local overheating, was the real cause of engine failure. This hypothesis presumes that preignition is induced before the local overheating becomes severe enough to cause injury directly.

Descriptions of injuries to engine parts that have been attributed to knock have been written by Midgley (reference 2), Pye (reference 3, pp. 90-114), Gagg (reference 4), Wood (reference 5), and others. In no case, however, was adequate evidence included to show that preignition did not exist.

This paper presents the results of an investigation conducted by the NACA at Langley Memorial Aeronautical Laboratory, Langley Field, Va., during the summer of 1942 for the purpose of determining whether knock without preignition is injurious to engine parts. The operating conditions were the same in all tests, and the octane ratings of the fuels were so selected that no knock existed except in the second test and in the last part of the third test. Special care was taken to detect the presence of preignition or afterfiring.

APPARATUS

Figure 1 is a diagrammatic layout of the test engine and the associated equipment. The cylinder is a Wright C9GC having a $6\frac{1}{8}$-inch bore, a 7-inch stroke, and a compression ratio of 6.7. Inasmuch as the oil thrown from the crankshaft was inadequate to properly lubricate the cylinder walls, auxiliary lubrication for the cylinder was provided by orifices so located in the crankcase that oil sprayed on the walls of the piston and the cylinder. Additional oil was introduced into the cylinder through holes in the thrust and antithrust sides of the barrel at the limit of the crank-end travel of the piston-ring belt. New pistons were used in the first two tests but the piston used in the third test had been in prior service and was carefully cleaned before operation.

The fuel flow was determined by an electrically synchronized weighing scale and a stop watch. The combustion air was measured by a sharp-edge, thin-plate orifice installed according to A.S.M.E. standards (reference 6). A pressure pickup was used in conjunction with a cathode-ray oscilloscope and a recording oscillograph to observe and record cyclic pressure variations and to detect preignition.

TEST PROCEDURE

Three endurance tests were run to compare the conditions of cylinder parts after operation with and without knock.

Test	Knock	Duration of test (hr)
1	No knock	25
2	Violent knock	2.08
3	No knock Light knock	3 5.6

Specified engine-operating conditions for all tests were as follows:

Engine speed, rpm	2200
Indicated mean effective pressure, pounds per square inch . .	220
Fuel-air ratio	0.080
Temperature of rear spark-plug bushing, $^{\circ}$F	450
Combustion-air temperature, $^{\circ}$F	100
Spark advance, degrees B.T.C.	20

After the engine was run for 25 hours without knock (test 1), it was thoroughly inspected and was then reassembled with a new cylinder and piston.

A trial was made to find the correct blend of two fuels to give a knock-limited indicated mean effective pressure approximately 10 percent below the indicated mean effective pressure prevailing in test 1. The fuel finally selected had a knock-limited indicated mean effective pressure of 203 pounds per square inch.

Prior to test 2, the engine was given a run-in period of 5 hours under power, after which the knock limit of the fuel blend was checked. The engine was then run for 2.08 hours at the specified test conditions, which were 10 percent above the knock limit of the fuel. Overheating of the cylinder made it necessary to terminate the test after 2.08 hours The ignition was cut off at the termination of the test while the engine was still operating at full power but no afterfiring was observed.

Before test 3 was conducted, two lubricating-oil holes were drilled through the cylinder flange into the thrust and antithrust sides of the cylinder wall at the lower limit of travel of the piston-ring belt. The engine was again given a run-in period of 5 hours, after which it was run at the test conditions for 3 hours using Army 100-octane fuel. The engine did not produce audible knock with the 100-octane fuel. After the first part of test 3 was completed, the engine was disassembled and the piston was photographed.

The last part of test 3 was made at the test conditions with a fuel blend intended to give a knock-limited mean effective pressure 10 percent below the specified operating indicated mean effective pressure of 220 pounds per square inch. During the test, the operator continually made observations to detect preignition. Occasionally the ignition was momentarily cut off to detect the presence of afterfiring. Records of the pressure-time cycles were frequently made with the recording oscillograph.

Knock during this part of the test seemed to be somewhat lighter than that observed in test 2; therefore, after 3.5 hours of testing the knock limit was checked and found to be at an indicated mean effective pressure of 216 pounds per square inch. The engine was shut down and a fresh mixture of the same blend of fuels was put into the fuel tank. The knock limit was again checked and found to be at the original level of an indicated mean effective pressure of 203 pounds per square inch. The endurance test was then resumed and the run of 5.6 hours was completed. At the end of the tests, the ignition was cut off while the engine was operating at full power. There was no evidence of afterfiring.

RESULTS

History of tests. - A record of test 1, the 25-hour endurance test without knock, is shown in figure 2. The cylinder temperatures were reasonably stable except during the fifth hour when the cooling-air pressure accidentally fell to 3.6 inches of water. The test was successfully completed without injury to cylinder or piston.

Figure 3 shows the history of test 2. The knock produced in this test made a loud noise and was considered violent. It may be seen that the cylinder temperatures were not stable but continued to rise. The test was terminated because the cylinder temperatures became so high that seizure of the piston was feared.

The record of test 3 is shown in figure 4. During the knocking period of 5.6 hours, the cylinder temperatures were not appreciably higher than in the first part of the test without knock. No signs of preignition were detected either by cutting off the ignition or by observing the oscilloscope. A portion of a record from the oscillograph is shown in figure 5. Failure of the oscillograph prevented observation of the cycles during the last hour of the test.

The variation in knock limit encountered during the second part of test 3 is thought to have been caused by excessive amounts of oil in the cylinder. The knock limit in part 2 of test 3 was determined after the engine had been motored for some time and was found to be

at the prescribed indicated mean effective pressure of 203 pounds per square inch. When the knock limit was checked after prolonged engine operation at high power, however, it was found to have increased to an indicated mean effective pressure of 216 pounds per square inch. Accumulation of oil in the combustion space during the motoring period probably resulted in an apparent knock limit which was below the true knock limit of the fuel. After the engine had been operated for some time under power, most of the excess oil was burned away and the observed knock limit then approached the true knock limit of the fuel in the engine.

Conditions of pistons and cylinders. - Inspection of the engine after test 1, 25-hour endurance test without knock, showed that the cylinder and piston were in good condition. These parts were subsequently used in cylinder-cooling tests.

Figures 6 and 7 show that the pistons were injured in tests 2 and 3, in both of which knock occurred. The carbon deposits in the injured regions were either eroded or burned away. The zones in which the piston was injured are sharply defined. Figure 6(b) shows a magnified view of an injured area on one of the pistons. In the upper portion the crown was not injured but in the lower portion the aluminum was badly burned.

The location of the spark plugs and the spark timing were such that the end zones of combustion occurred in the regions bounded by the burned areas on the pistons. The cylinder head was also injured in areas adjacent to the combustion end zones. These melted areas may be seen in figure 8. In test 2 the piston was much more badly burned at a position corresponding to the inlet end zone, in which knock was apparently more violent than in the exhaust end zone. In test 3 injury to the piston and cylinder head did not occur in the exhaust end zone.

Figure 9 is a photograph of the piston operated in the engine without knock for 3 hours. The crown was uninjured and was covered with a heavy deposit of carbon. The carbon was removed from one half the piston crown before photographing in order to expose the crown surface.

DISCUSSION

Absence of surface ignition. - The results herein reported do not conclusively demonstrate that knock causes direct injury nor that knock must first induce surface ignition before causing injury. There is evidence, however, that knock leads to the injuries observed and that surface ignition was absent. Two phenomena which show that knock does lead to the aforementioned injuries are:

1. The piston and the cylinder were injured when tested in the presence of knock but remained uninjured when operated without knock.

2. Injury occurred only on the surfaces adjacent to the combustion end zones, where the knocking reaction takes place.

The improbability of the occurrence of surface ignition during these tests was displayed by two more phenomena:

1. The absence of preignition was positively demonstrated and, furthermore, no indications of afterfiring were observed, although thorough efforts were made to detect its presence.

2. In the two cases of injury observed in this investigation, the most severe damage occurred on the surfaces adjacent to the intake end zone, which is normally the coolest portion of the combustion chamber.

Effect of knock on cylinder temperatures. - Figure 3 shows that cylinder temperatures of an engine operated with violent knock were not stable but continued to rise. When the engine was operated under similar conditions but without knock, the cylinder temperatures remained fairly stable, as may be seen from figure 2. The phenomenon of continually rising engine temperature, sometimes referred to as "runaway temperature," has been observed and discussed by Rubenz (reference 7) and by Veal (reference 8).

It is possible that the increased heat transferred to the surfaces around the combustion end zones gradually heats the other parts of the cylinder. Under conditions of light knock the temperatures were stabilized.

It is widely recognized that knock results in increased heat transfer to the cylinder. Results of the investigation herein reported support this belief. Light knock resulted in a slight increase in required cooling, and violent knock resulted in cylinder temperatures so high that it was necessary to discontinue the test.

CONCLUSIONS

Results of endurance tests of 2 hours with violent knock and 5.6 hours with light knock on a Wright C9GC cylinder compared with the results of a 25-hour endurance test without knock indicate:

1. Continuous knock caused injuries to the aluminum surfaces of the combustion chamber without inducing preignition.

2. Violent knock tended to increase cylinder temperatures gradually, but light knock had little effect.

3. In the cylinder tested, knock was more destructive in the inlet end zone than in the exhaust end zone.

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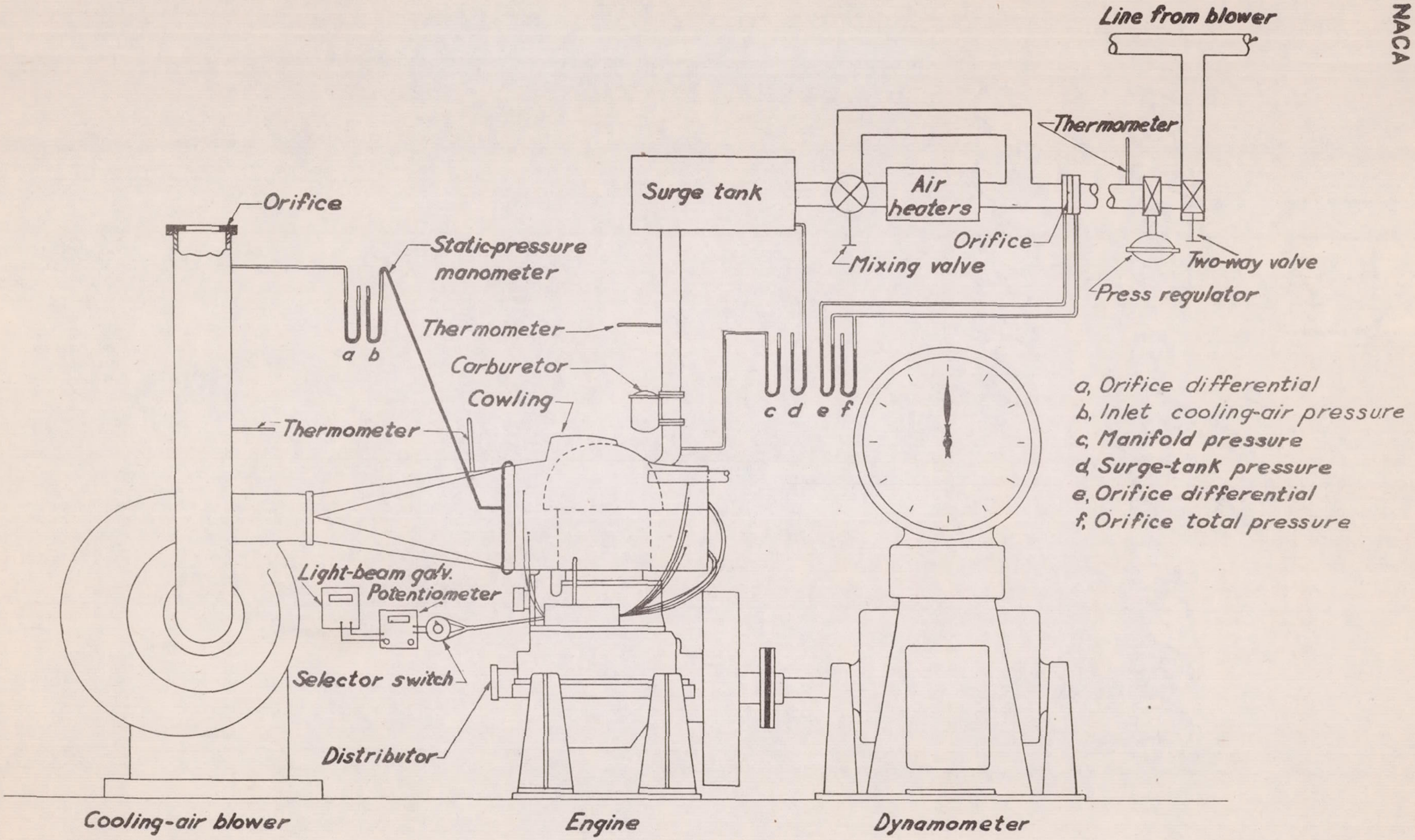

Figure 1 .-Diagrammatic layout of equipment.

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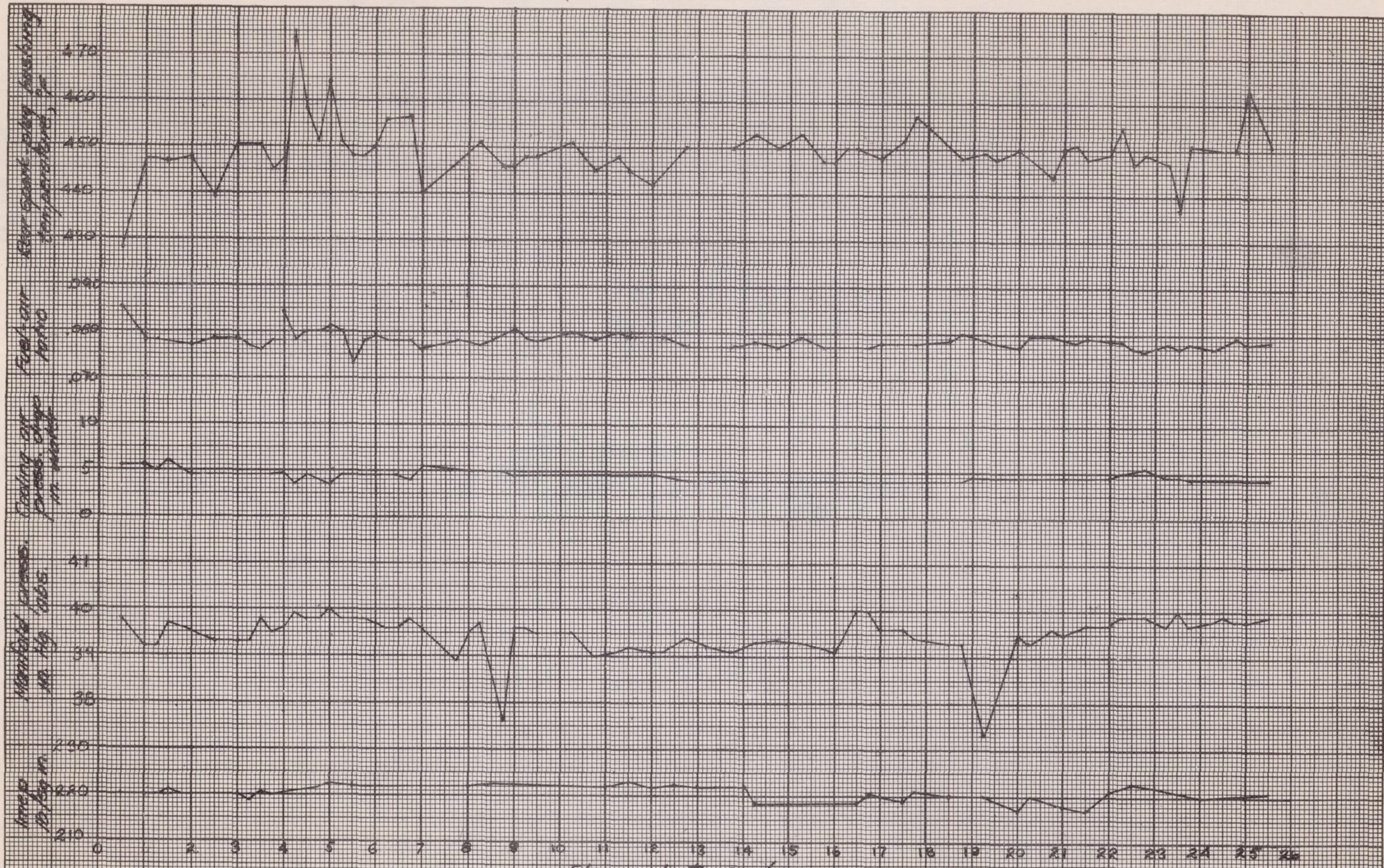

Figure 2 - Test 1, endurance test without knock. Engine speed 2200 rpm; spark timing 20° B.T.C.; compression ratio 6.7; inlet-air temperature 100° F; average cooling air temp. 80° F; Wright C9GC cylinder.

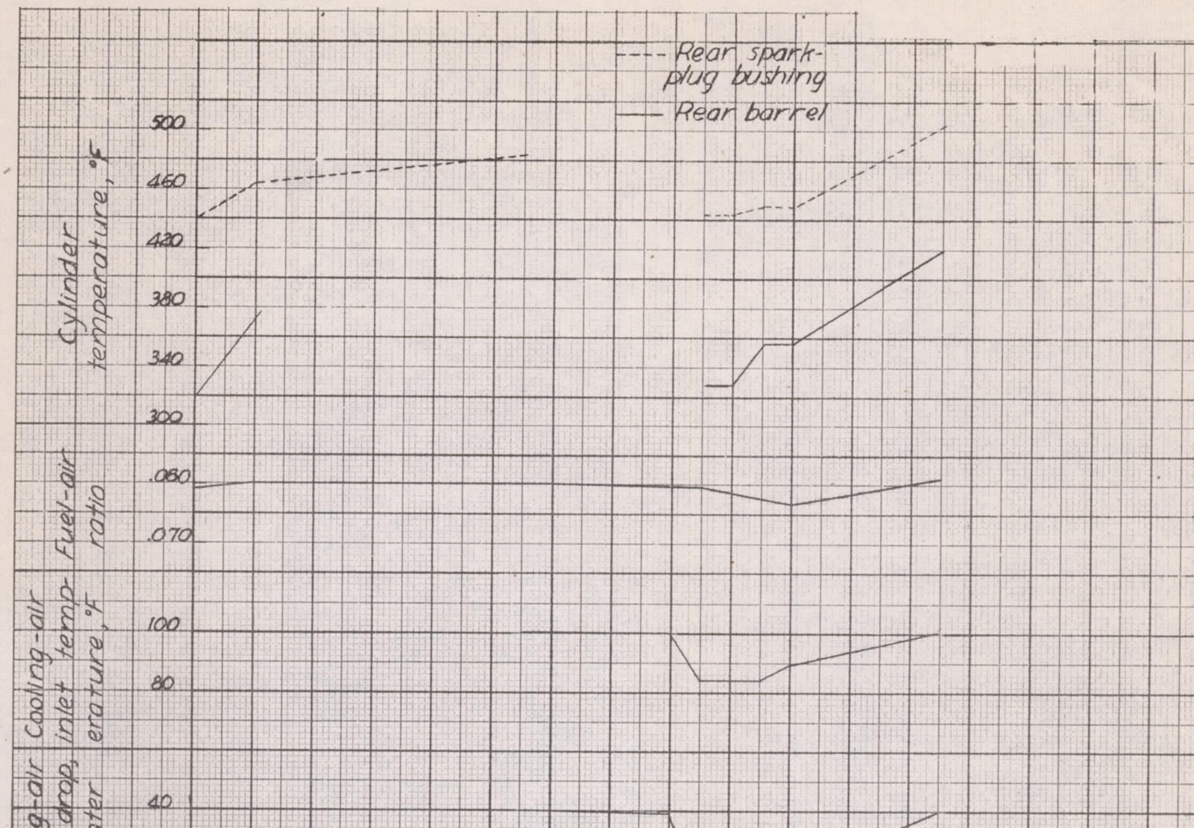

Figure 3.- Test 2, endurance test with knock. Knock-limited indicated mean effective pressure, 203 pounds per square inch; engine speed, 2200 rpm; spark timing, 20° B.T.C.; compression ratio, 6.7; inlet-air temperature, 100°F; Wright C9GC cylinder; manifold pressure, from surge-tank manometer.

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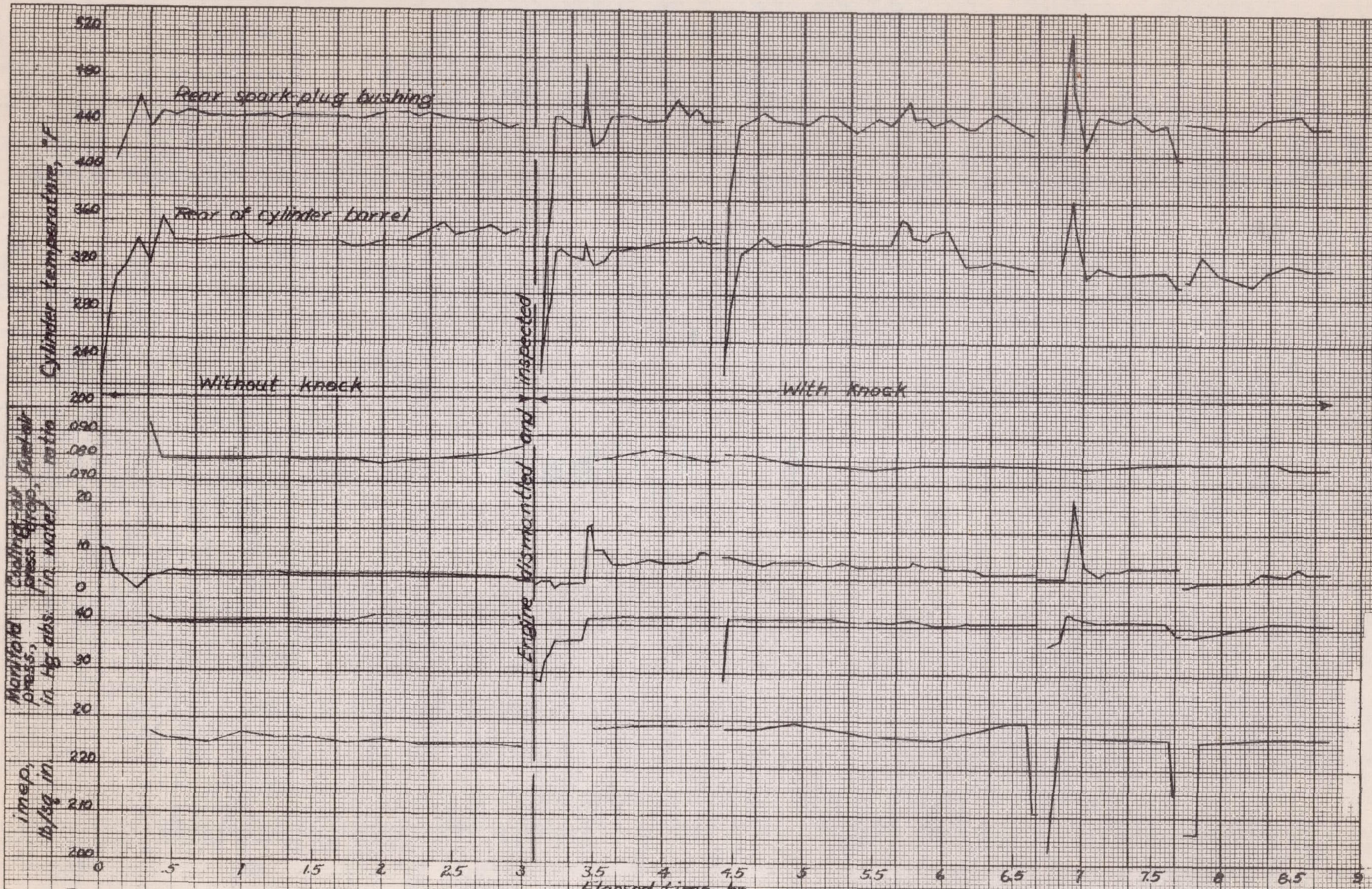

Figure 4.- Test 3, 3 hours without knock and 3.6 hours with knock. Engine speed, 2200 rpm; spark timing, 20° B.T.C.; compression ratio, 6.7, inlet-air temperature, 100°F; average cooling-air temperature, 85°F; Wright C9GC cylinder.

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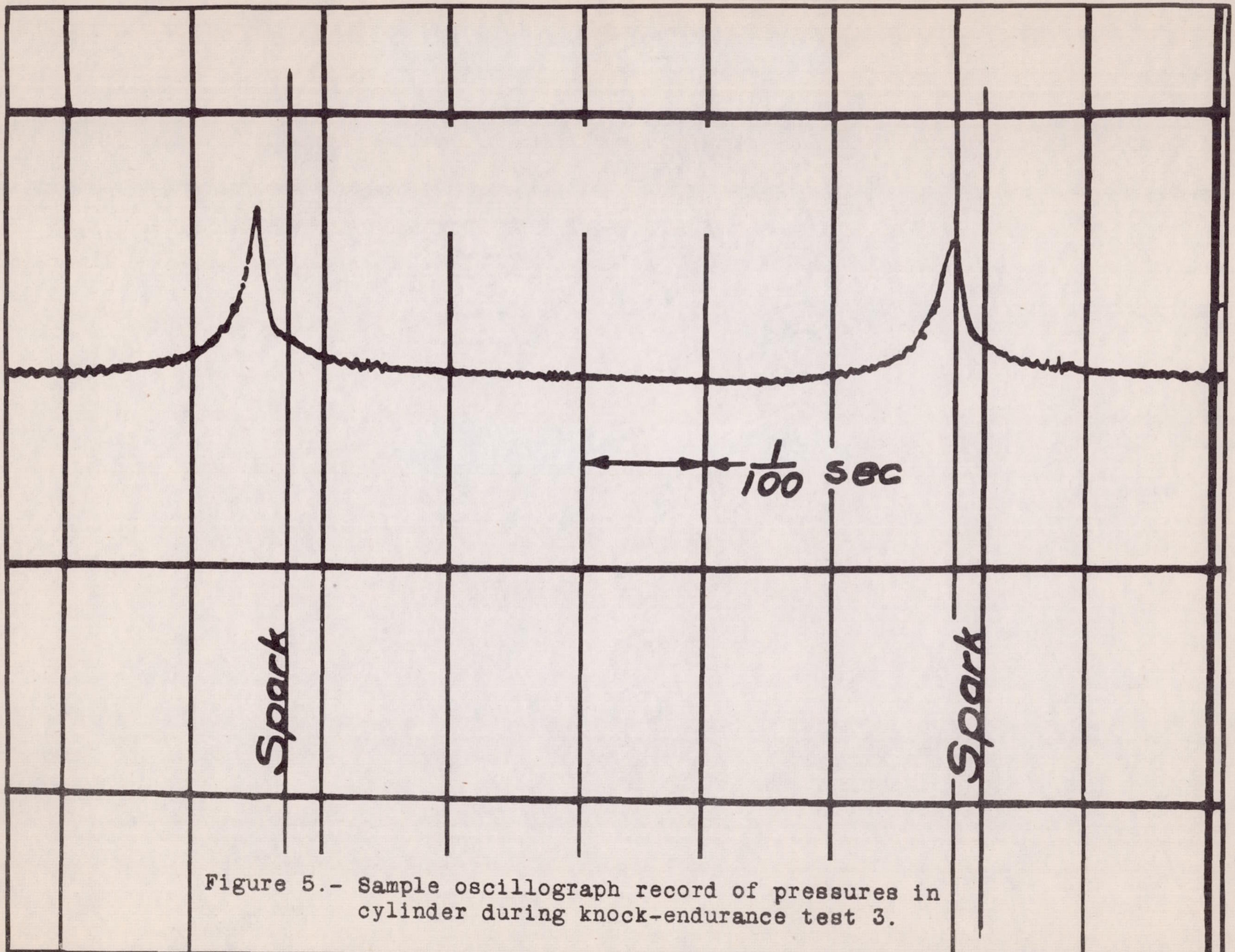

Figure 5.- Sample oscillograph record of pressures in cylinder during knock-endurance test 3.

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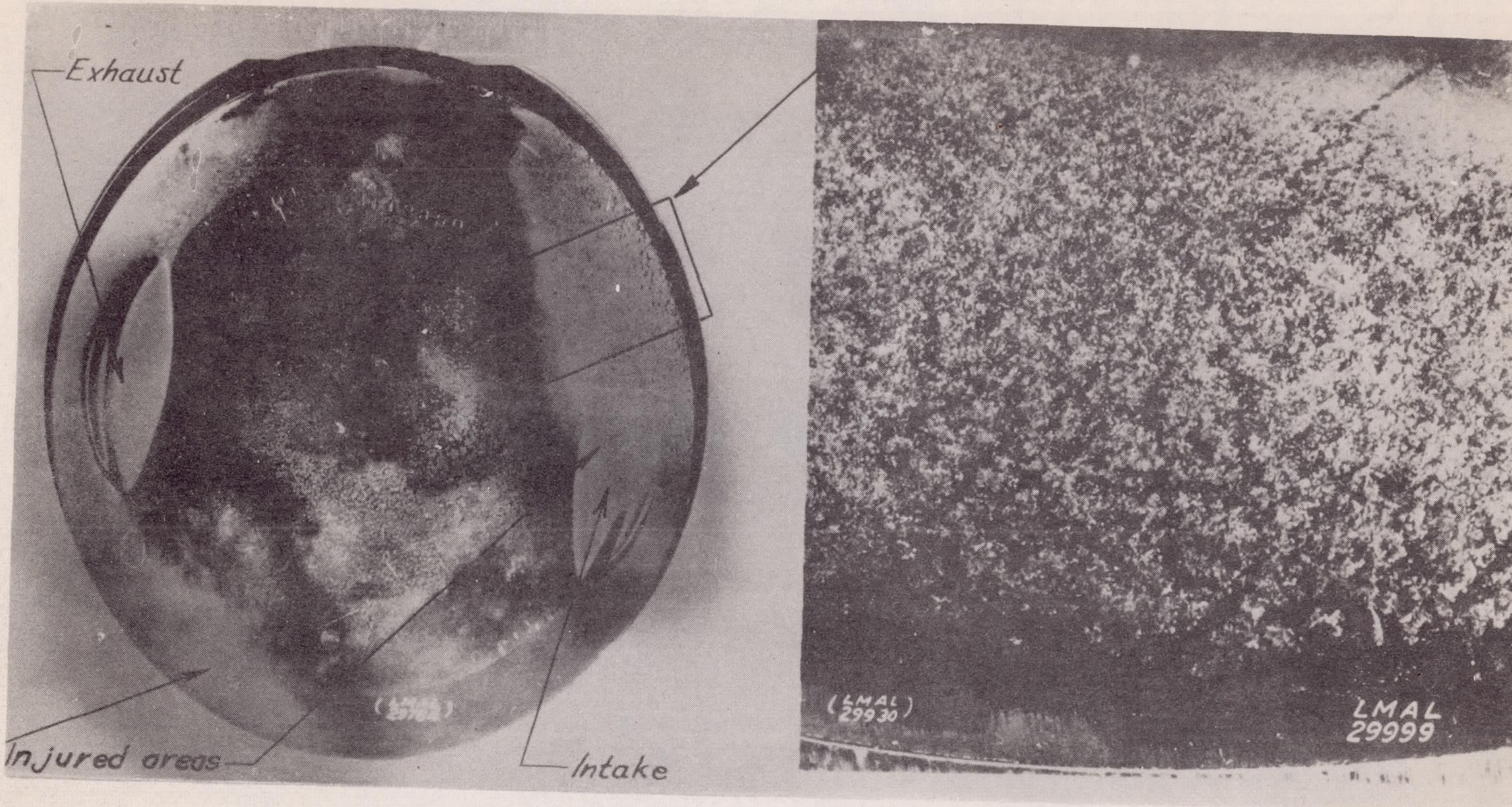

(a) Piston crown

(b) Injured area on piston crown X2.2.

Figure 6.- Test 2, piston tested for 2 hours under condition of violent knock. Indicated mean effective pressure, 226 pounds per square inch; engine speed, 2200 rpm; fuel-air ratio, 0.080; Wright C9GC cylinder.

Fig. 6

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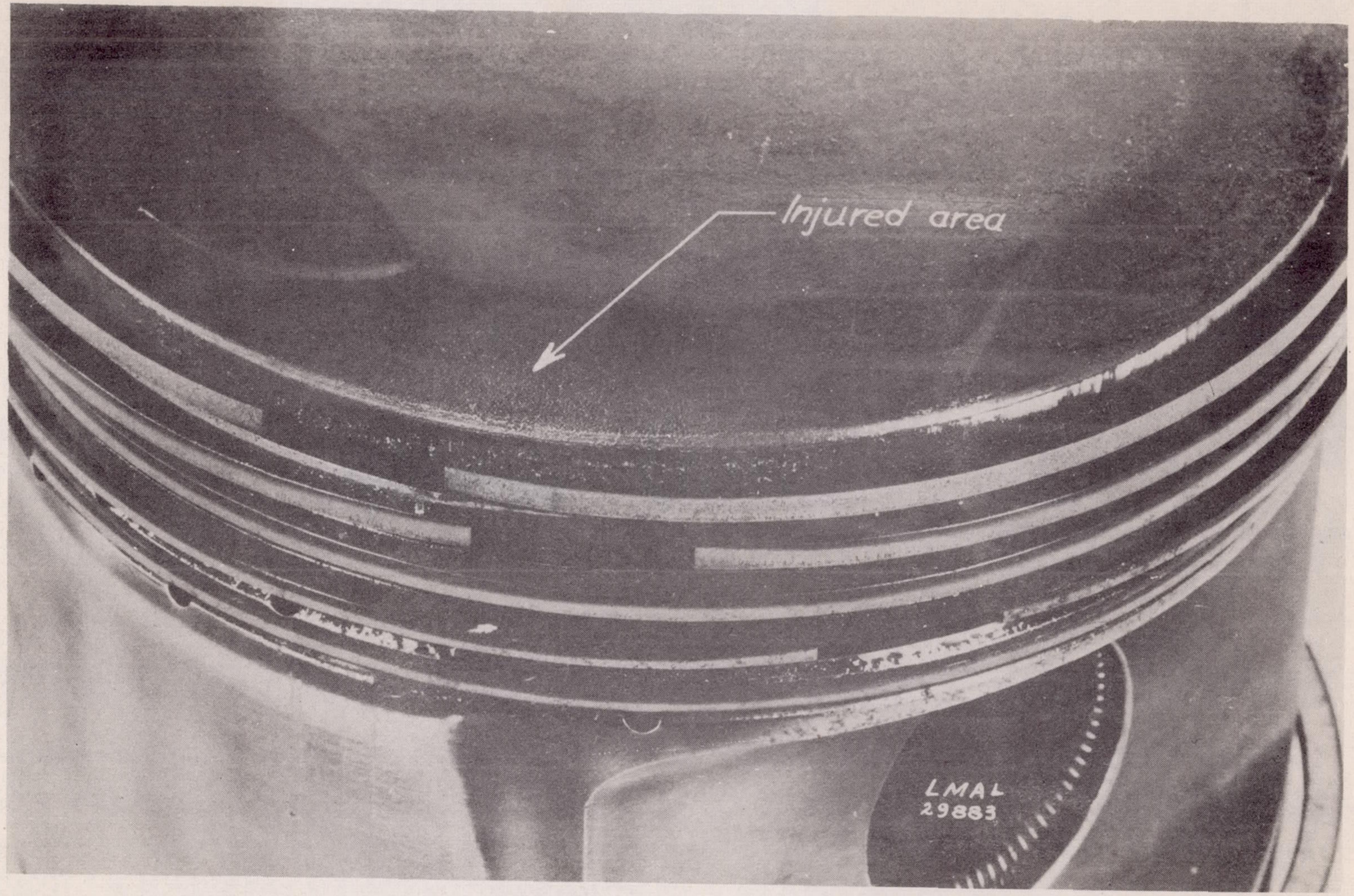

Figure 7.- Test 3, piston tested for 5.6 hours under conditions of light knock. Indicated mean effective pressure, 226 pounds per square inch; engine speed, 2200 rpm; fuel-air ratio, 0.080; Wright C9GC cylinder.

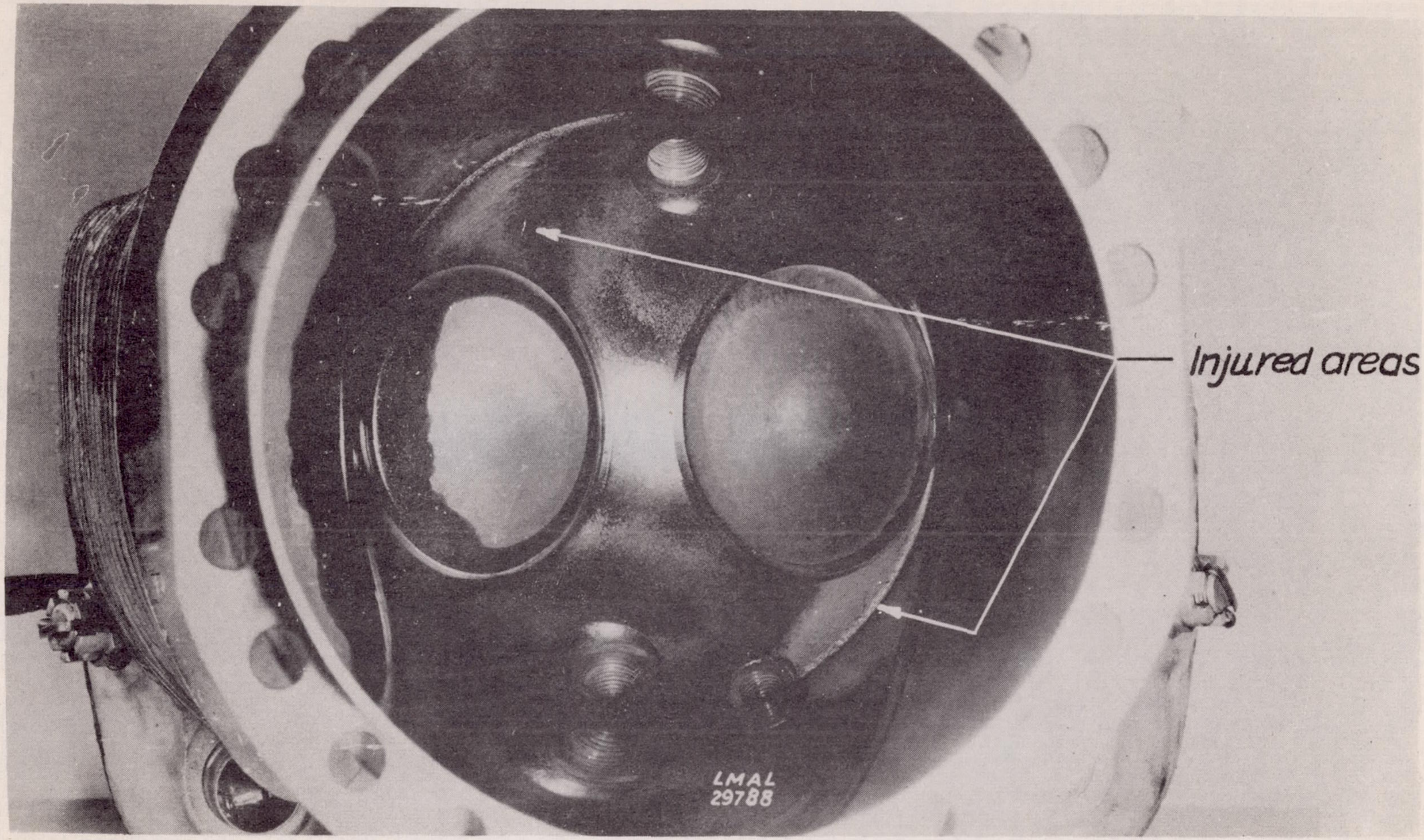

Figure 8.- Injury of cylinder head resulting from test 2, a 2-hour test with violent knock. Indicated mean effective pressure, 226 pounds per square inch; engine speed, 2200 rpm; fuel-air ratio, 0.080; Wright C9GC cylinder.

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NACA Fig. 9

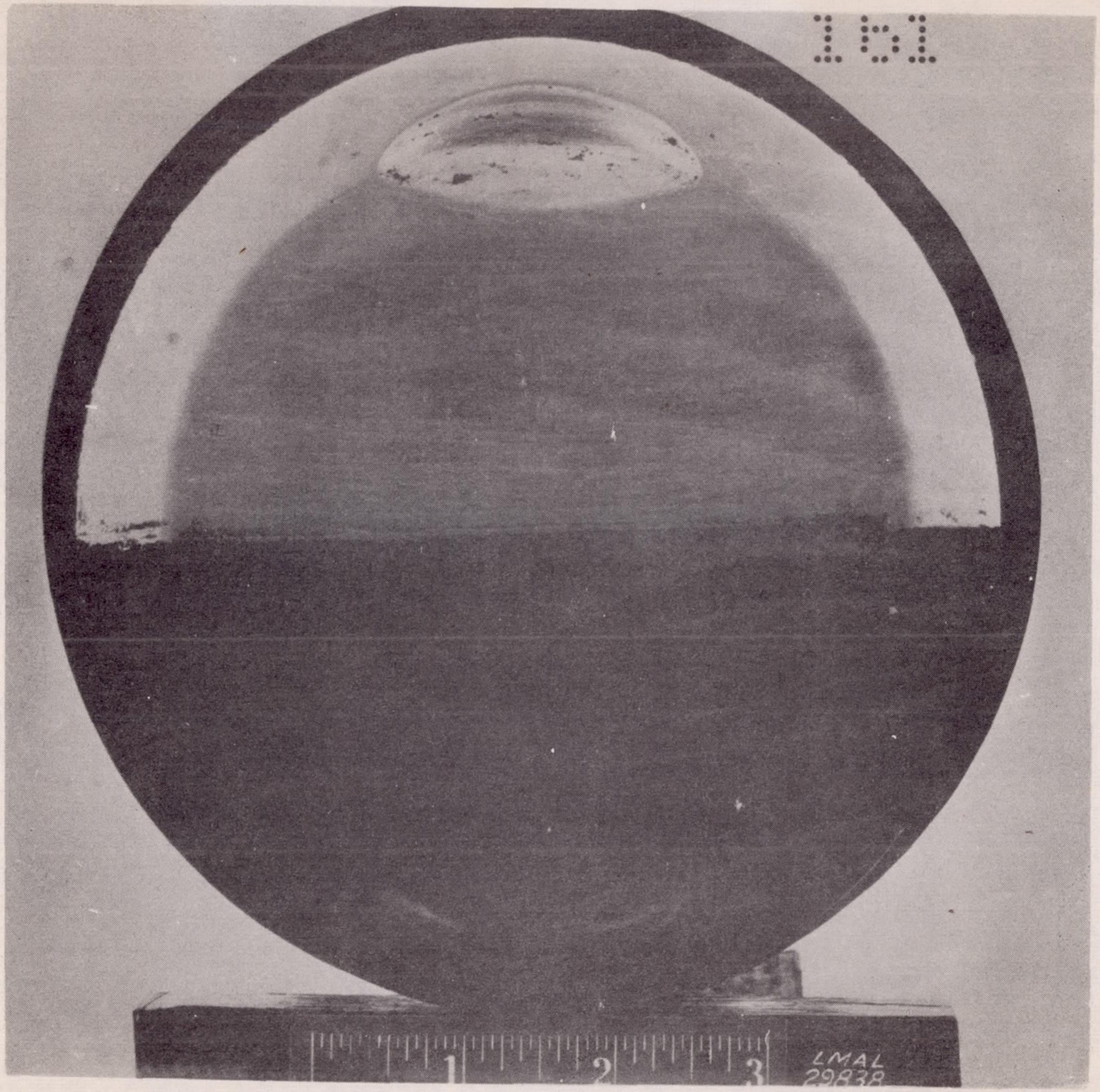

Figure 9.- Test 3, piston used in 3-hour test without knock. Indicated mean effective pressure, 226 pounds per square inch; engine speed, 2200 rpm; fuel-air ratio, 0.080; Army 100-octane fuel; Wright C9GC cylinder.